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DETECTING TRENDS IN HARBOR PORPOISE ABUNDANCE USING AERIAL SURVEYS: A PRELIMINARY REPORT BASED ON THREE YEARS

By

Karin A. Forney, Doyle A. Hanan and Jay Barlow

ADMINISTRATIVE REPORT LJ-89-20

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Detecting Trends in Harbor Porpoise Abundance Using Aerial Surveys: A Preliminary Report Based on Three Years

Karin A. Forney
Southwest Fisheries Center
National Marine Fisheries Service
P.O. Box 271
La Jolla, CA 92038

Doyle A. Hanan
California Department of Fish and Game
c/o Southwest Fisheries Center
P.O. Box 271
La Jolla, CA 92038

and

Jay Barlow
Southwest Fisheries Center
National Marine Fisheries Service
P.O. Box 271
L Jolla, CA 92038

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Detecting Trends in Harbor Porpoise Abundance Using Aerial Surveys: A Preliminary Report Based on Three Years

K. A. Forney, D. A. Hanan and J. Barlow

ABSTRACT

Aerial surveys of harbor porpoise, Phocoena phocoena, were conducted in autumn, 1986-88. The number of porpoise seen per kilometer of survey effort was used as an index of abundance. Based on these surveys, an analysis of covariance with year as the covariate was used to model porpoise abundance. Monte Carlo simulations were performed to determine the power of this model to detect trends in abundance. We conclude that the ability to detect trends is poor if traditional levels of statistical significance are used. However, if a larger α-error is accepted, the ability to detect trends increases substantially. Additional survey years similarly improve the power to detect trends.

INTRODUCTION

Harbor porpoise (Phocoena phocoena) are caught incidentally during halibut fishing with gill nets along the central California coast (Diamond and Hanan 1986; Hanan, Diamond and Scholl 1986, 1987; Barlow 1987). To assess the potential impact of this fishery mortality, ship and aerial surveys have been used to estimate the abundance of harbor porpoise along the coast of California, Oregon, and Washington (Barlow 1988; Barlow, Oliver, Jackson, and Taylor 1988). These authors showed that although aircraft can be used to survey a large area very quickly, abundance estimates from aerial surveys must be multiplied by a very large and uncertain correction factor to account for the majority of animals that will be underwater at any given instant. For this reason, ship surveys were concluded to be preferable for estimating absolute porpoise abundance.

The requirements are, however, less stringent if the only goal is to detect trends in the abundance of porpoise over time. The ability for aircraft to cover great distances relatively quickly and inexpensively make them a logical platform for such surveys. If the fraction of animals that are visible from the air does not change over time, the correction factor becomes irrelevant, and indices of relative abundance can be used in place of absolute abundance measures.

In this preliminary report, we describe a series of three aerial surveys for harbor porpoise conducted in central California during autumn of 1986, 1987, and 1988. These surveys were designed specifically to detect changes in porpoise abundance. We used a chartered twin engine aircraft to fly predetermined transect lines which zigzagged up the coast between Point Conception and the mouth of the Russian River (Figure 1). Line transect methods were used with one observer on each side of the aircraft and a belly-port observer. A fourth person recorded information pertaining to sightings of porpoises and sighting conditions. Each year within the survey period, the transect lines were repeated between 3-7 times, depending on weather conditions.

The number of porpoise seen per kilometer of search effort is used as a measure of relative abundance. Non-parametric ANOVA is used to determine which sighting conditions significantly affect porpoise per kilometer. The significant factors are included in an ANCOVA model using year as the covariate. Standard tests are applied to determine whether trends with year are significant. Monte Carlo methods are used to determine the actual power of this test to detect known trends in abundance.

METHODS

Field methods

The surveys were established to monitor changes in abundance within the range of porpoise/gill net fishery interactions (Point Conception to the Russian River, California). Prior to any survey, weather conditions were checked at numerous locations along the survey path. Surveys were started only when there was a good likelihood of completing at least half of the survey (Point Conception to Monterey or Monterey to the Russian River) under good conditions. Surveys were halted when viewing conditions deteriorated below acceptable levels (Beaufort higher than 4 or 5, excessive dark cloud cover, rain, or fog) as determined by the survey leader.

Each flight was assigned a unique flight number. A series of predetermined locations (waypoints) marked the beginning and end of each transect and were entered into the LORAN C navigational receiver giving the pilot a course to follow. The waypoints were laid out to zigzag in a generally northward progression up the coast from shore roughly to the 50 fathom contour on one transect and then back to shore on the next transect (Figure 1). The transect lengths ranged from 2.8 miles to 24.2 miles and averaged 13.4 miles. The flights were flown at an altitude of approximately 213 meters and speeds of 90-100 knots. To reduce sun glare, surveys were only conducted from south to north.

The surveys were flown in a twin engine, high wing, seven passenger aircraft (Partenavia P68). Three observers were utilized: one observer sat in the seat behind the pilot and looked out a left side window; the second observer sat behind the copilot position and looked out a right side window; and the third observer (belly observer) lay on his/her stomach just behind the right-side observer's seat to survey the water directly below the airplane through a 10 by 12 inch rectangular viewing port. The rear bench seat was removed to allow the belly observer to lie flat on the floor. For the 1988 survey only, the side windows were fitted with plexiglas curved out to form bubble-type windows allowing the side observers to see from the horizon to directly under the plane. This created an overlap with the belly observer's field of view, especially on the right side. However, this overlap did not result in duplicate sightings because the observers were in constant communication and discussed all possible sighting duplicates as they occurred.

The data recorder was seated in the copilot position and recorded data as it accumulated into a flight log of location (latitude and longitude), time, sighting conditions, and porpoise sighting information. To simplify the recording procedure and enhance the accuracy of the data, a lap-top computer was used to replace the flight log for the 1988 survey and was connected to the airplane's LORAN C navigational receiver via RS232 ports to constantly update the location.

The pilot, recorder, and observers communicated through headsets and voice activated microphones. All communication was recorded on a central tape recorder. Additionally, each observer used a hand-held tape recorder for individual storage of sighting information. The two side observers used hand-held inclinometers to measure declination angles in degrees to the animals sighted. Due to space limitations, the belly observer estimated angles using marks applied to the view port with a grease pencil. The observers changed positions approximately every 1-1.5 hours and between flights.

When describing viewing conditions, the side observers each split their field of view horizontally into two areas delineated by angles of declination ("inside", 90 to 35 degrees and "outside", 36 degrees to the horizon). The observers reported sighting conditions separately for the "inside" and "outside" areas. The belly observer reported sighting conditions for his/her whole field of view (65 degrees left to 60 degrees right). Each observer determined the sighting conditions for his/her position in the airplane as excellent, good, poor, or "off effort", depending on estimated viewing depth into the water, sun glare, and water color contrast. They monitored those conditions constantly and called out any changes to the recorder who entered those changes, the time, and the location into the

flight log or computer. The observers were considered "on effort" from start to finish of a leg, except when circling or when they called themselves "off effort" because of poor sighting conditions.

The surveys began with the pilot alerting the survey team of approaching waypoints and then announcing "on effort" at the waypoint demarcating the beginning of a transect or "off effort" as the ending waypoints were passed. Because many waypoints served as the end of one transect and the beginning of another, the team
simultaneously went off effort for one transect and on effort for the subsequent one. With the announcement of "on effort", the recorder began entering current weather and sighting conditions, while the observers began scanning their field of view for porpoise.

When porpoise were sighted, the observer called out, "sighting" and measured the declination angle to the sighting, while determining the number of animals sighted. At the same time the recorder assigned a sighting number and announced it to all observers. The observer then recited the sighting number, time, declination angle, species, and number of animals into his/her hand held tape recorded. This procedure was followed because there were often a series of sightings by one or more observers in rapid succession and the data recorder could not possibly enter all the data as the sightings occurred. When the recorder was ready for the information, he/she requested it from the observers in succession by sighting number. The pilot was asked to circle on porpoise sightings if there was any question about species identification or number of porpoise. During the circling, additional sightings were recorded as "off effort" sightings. Sightings by the pilot or recorder were also recorded as "off effort" and were discouraged to eliminate observer sighting bias.

During the first survey year (1986), all marine mammals were included in the survey and observers reported any marine mammals sighted. However, the large number of California sea lions sighted seemed to result in some confusion during this survey so only harbor porpoise were included during the second two surveys (1987 and 1988). This allowed the observers to concentrate on harbor porpoise for sightings, identification, and enumeration.

Following the surveys, the data in the flight log or computer were checked for accuracy and compared to the tape recorded conversations. The data were entered into microcomputer data bases for summary and analysis. The data and summaries were submitted to the National Marine Fisheries Service, Southwest Region (NMFS, SWR) as final reports of each survey to fulfill contractual requirements between California Department of Fish

and Game (CDFG) and NMFS (Hanan 1987, 1989; Hanan and Jones 1988).

Analytical methods

Each segment of flight during which all conditions were constant was considered a separate unit. Segments with the same conditions could thus be combined to stratify by different factors. These factors included Beaufort sea state, cloud cover, surface penetration, observer position, individual observers, and three different geographic stratifications. The geographic categories included transect number (see Figure 1), the regions of the coast defined by Barlow et al. (1988), and an ad hoc subdivision into four areas chosen on the basis of apparent porpoise abundance (Figure 2). The latter geographic stratification was used in the analysis of covariance described below in order to avoid the confounding effect of changing geographic coverage between years. Cloud cover was recorded as a percentage and later coded into the following categories: clear (0-24%), partly cloudy (25-59%), mostly cloudy (60-90%), and overcast (91-100%).

Once the data were structured in the above manner, two- and three-way stratification tables were created so that factors which might influence apparent porpoise abundance could be tested. Non-parametric tests were used, as the data violate the assumption of normality required for parametric tests. For each set of stratification criteria, four tables containing the following information were created: number of sightings, number of porpoise seen, number of kilometers flown, and porpoise seen per km flown.

To compare values of porpoise per km for different conditions, three replicate measures of density were created for each cell by randomly assigning flight segments as replicate 1, 2 or 3. For one-way comparisons, the Kruskal-Wallis single-factor analysis of variance was used (Kruskal and Wallis 1952). For two-way comparisons, we used a two-factor extension of the Kruskal-Wallis test (Zar 1984; Scheirer, Ray and Hare 1976).

Based on the results of these tests, the following model was chosen to describe the effects of Beaufort sea state, cloud cover, area and year on logarithmic estimates of porpoise per kilometer:

$$P = \overline{P} + \alpha_{Bi} + \alpha_{Sj} + \alpha_{Ak} + \beta^{*}(Y-\overline{Y}) + \epsilon_{i,j,k,Y} \qquad (1)$$

where P = $\log_e$ of [(porpoise/km) + 1].

$\overline{P}$ = mean value of P

α_{Bi} = effect of Beaufort condition i on P.

α_{Sj} = effect of cloud cover j on P.

α_{Ak} = effect of area k on P.

β = factor representing yearly trend.

Y = current year.

$\bar{Y}$ = mean year.

$\epsilon_{i,j,k,Y}$ = normally distributed error term with mean zero.

The parameters for this model were estimated using an analysis of covariance (ANCOVA using SAS procedure GLM; Joyner 1985). Year was represented as a covariate to detect trends in yearly abundance, measured as the natural logarithm of porpoise seen per kilometer. A logarithmic transformation was used to make the data more nearly normal. A value of one was added to each estimate before transformation to avoid taking the logarithm of zero (Zar 1984). Because of the logarithmic transformation, a linear increase or decrease in the year covariate would be interpreted as an exponential increase or decrease in porpoise abundance. In the ANCOVA, each cell is weighted by the number of kilometers flown under the respective set of conditions, because the assumption of equal representation of all cells is not met.

Monte Carlo simulations were performed to determine the power of the ANCOVA to correctly detect a given trend in porpoise abundance. A series of random data sets were generated, based on the parameter estimates obtained from the actual data (see results) excluding the effect of year, and adding a random error term (ϵ in equation (1)). The error term was drawn from a distribution with mean zero and a variance which was equivalent to the variance of the error term obtain in the weighted ANCOVA of the actual data (Root MSE = .353). Because a weighted analysis was used, when the simulation data were generated, the error term was weighted inversely, i.e. multiplied times $\sqrt{1/w}$, where w is the number of kilometers flown under the conditions for each cell. A value for w was obtained by randomly selecting one of the three survey years' km flown values to be used for each simulated year of data. A yearly trend was incorporated into the simulation data by modifying the covariate β. When these data sets with known conditions were analyzed in an ANCOVA, the proportion of time the procedure correctly detected a given trend in abundance was equivalent to its power.

RESULTS

Porpoise seen per km

Variables thought to potentially influence apparent porpoise per km were tested individually in one-way non-parametric tests. These tests revealed no significant differences in porpoise seen per kilometer with changing conditions of Beaufort ($p>.25$), degree of cloud cover ($p>.10$), years ($p>.25$), surface penetration codes ($p>.10$), and with different observers ($p>.10$). However, when Beaufort sea state categories were combined, it was determined that the number of porpoise seen at Beaufort 1&2 was significantly higher than the number seen at Beaufort 3&4 ($p<.05$). Similarly, more porpoise were seen under clear skies than when greater than 24% cloud cover was present ($p<.05$).

Because the effects of some variables were likely to be confounded and therefore not detected in one-way tests, additional two-way tests were performed including combinations of degree of cloud cover, Beaufort sea state, surface penetration, year, and area of the coast. Four areas of the coast (1-4) were defined based on apparent patterns of harbor porpoise abundance (Figure 2). In all of the two-way tests, Beaufort sea state and cloud cover significantly affected porpoise seen per kilometer. The different areas of the coast also showed significant differences. Surface penetration was significant in only one test and was not significant when tested with other measures of sighting condition. Year was not significant. In all of the combinations, the interaction effects were not significant. The tests and resulting probability levels are summarized in Table 1.

The results of the ANCOVA for the 1986-88 harbor porpoise data are shown in Table 2. The effects of Beaufort sea state, cloud cover and area were significant ($p < 0.005$) The effect of year was not significant. The ANCOVA parameter estimates are displayed in Table 3 for both weighted and unweighted analyses for comparison. For the simulations, however, only the weighted parameter estimates are used.

Analysis of power to detect trends

The initial set of random data simulates three survey years with no change in abundance and was used to determine the reliability of the procedure. 300 data sets were generated and analyzed. A count of the number of times a significant trend was found, even though none was actually present, represents the α-error. At the $\alpha=0.10$ and $\alpha=0.05$ levels, $31/300=0.103$ and $16/300=0.053$ significant trends were found, respectively. Thus the actual α-error in this procedure appears equivalent to the theoretical one. The error term (Root MSE) obtained for these data sets was also close to the original error in the actual data (Root MSE = 0.353), with a mean of 0.351 (S.D.=0.026). The

estimates of the covariate for year in the simulated data were normally distributed with a peak roughly at zero (Figure 3). These results confirm that the procedure can reliably create and process simulated data without introducing bias or errors.

To support the results of the ANCOVA that no yearly trend is evident in the 1986-88 survey data, the covariate term estimated with the weighted analysis of the actual data was compared to the distribution of covariate estimates obtained with the 300 random data sets representing no yearly change. It was found that the estimate falls close to the center of the distribution of values (Figure 3). This provides further support that the 1986-88 data show no evidence of a yearly trend.

Next, random data sets spanning more than three years were created, and an artificial yearly trend was incorporated into the data. All other parameters were taken from the analysis of covariance of the weighted actual data (Table 3). Analysis of covariance of the resulting data sets demonstrates the ability of this procedure to detect a given trend over a specified time period. The results provide guidelines for the number of years necessary to detect trends in porpoise abundance.

The levels of change in abundance tested include increases and decreases of 25% and 50% over 4 and 6 years, as well as no change over the same time periods. For each of these levels of change (10 total), 100 data sets were created and analyzed. A certain fraction of data sets yielded incorrect results, ie. a given trend was not detected (β-error), or a trend was detected when none was present (α-error). Based on the proportion of correct interpretations, the β-errors in Table 4 provide estimates of power of detecting trends correctly (power is equivalent to 1 - β-error) for several levels of α-error. The percent of time the sign of the covariate for year is estimated correctly, regardless of significance value, corresponds to an α-level of α=1. For $\alpha < 0.10$, the direction of change (i.e., increase or decrease) was correct in all simulations which showed a significant trend. However, as α-levels increased above 0.10, the incidence of detecting a significant trend in the opposite direction increased. In our analyses, however, this was a rare occurrence and further simulations would be required to assess the magnitude of this error.

DISCUSSION

The number of years necessary to detect trends in harbor porpoise abundance with the techniques described above will depend on two things: the rate of change in population size over the specified time period, and the degree of certainty desired. A 25% change will be more difficult to detect than a 50% change over the same time period. If a 50% change must occur before the

trend is detected, this may be too large to be of use in the management of populations. Also, problems can arise because, for example, a 50% decrease is more likely to be detected than a 50% increase. These difficulties can be counteracted by adjusting the degree of certainty that is required in the analysis, i.e., by raising the α-level used to determine statistical significance.

Although an α-level of 0.05 provides a good likelihood of detecting a 50% decrease in population size, the ability to detect the smaller decrease of 25% is very poor (Table 4). Increases in population size follow the same pattern, but are even harder to detect. If α-levels are raised, this improves the ability to detect trends, but also increases the likelihood of detecting a trend when none is actually present. In the context of ecological monitoring, Hinds (1984) suggests that the probability of detecting a false trend (α-error) should be made equal to the probability of not detecting a trend that is actually present (β-error). As is apparent in Table 4, however, the actual error levels will depend on the amount of change that is to be detected, as well as on the number of years to be surveyed. The level of α required to equalize α and β will increase as the level of change in abundance and the number of survey years decrease.

The most extreme form of raising α-levels is accomplished by considering only the sign of the estimate for the year covariate in the analysis of covariance, thus essentially making α=1. If only the sign of the estimate is used, regardless of the corresponding significance level, the probability of detecting a trend correctly is high for all levels of yearly change in abundance and number of years surveyed (Table 4). In the cases where no yearly trend was incorporated into the data, the number of positive and negative covariate estimates was roughly equal (+/- ratios of 50/50, 50/50, and 58/42 for 3, 4 and 6 years, respectively), so there should be an equal probability of misinterpreting surveys of a stable population to indicate that the population is increasing or decreasing.

Gerrodette (1984) suggests that this may be an acceptable approach to dealing with the management of rare species. If the cost of not detecting a population decrease is high relative to the cost of implementing restrictions on a stable population which is erroneously believed to be on the decline, then this strategy is preferable to strictly adhering to low α-levels. In terms of fisheries management, this approach also has the advantage of benefitting both the management agencies and the fishery industry. On the one hand, a decrease could be predicted with a higher degree of certainty and this would enable more rapid implementation of protection measures when necessary. On the other hand, the corresponding improved ability to detect an increase, which is indicative of a recovering stock, would

benefit the fishery because their harvesting restrictions could be relaxed.

The use of simulations allows researchers to estimate appropriate error levels for the analysis of surveys of animal populations. For the detection of trends in harbor porpoise abundance, we have found that a large change must occur before a trend can be detected using conventional α-levels of .05 or .10. However, if only the sign of the covariate is used as an indication of yearly trends in abundance, the likelihood of detecting a trend when present improves greatly. The absolute difference between the estimate and the mean values obtained through 'no trend' simulations can be used as an indication of the probability that the increase or decrease is actually occurring (i.e., the position of the covariate estimate relative to the peak in Figure 3). Adding additional years to the survey also increases the ability to detect trends. In our example, going from 4 to 6 years increases the power by roughly the same amount as going from a lower to a higher α-level (Table 4).

As in all models, there are some assumptions and caveats in the procedures we used. The most critical assumption is that the three years of data collected from 1986-1988 characterize the level of variability expected in a longer time series. In addition, the results are only accurate if the higher order interaction effects between individual parameters do not exist, i.e., if equation (1) is accurate. All of the non-parametric tests indicated that there were no significant interaction effects, but it is possible that such interactions are indeed present but not detectable. If this were the case, β-levels from the ANCOVA model we used would not be accurate. Finally, the simulations presented here consisted of 100 random data sets for each type of trend tested. The probability estimates are likely to improve with an increased number of simulated data sets, i.e., 300, such as were generated for the three year, no change simulation.

Additional surveys are scheduled for autumn 1989. After new data become available, we plan to update the results discussed above by performing more comprehensive simulations and similar analyses based on four years of aerial survey data. At that time, we intend to modify this report for publication.

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Table 1. Two-way tests to detect changes in apparent porpoise abundance with different conditions. Probability values refer to the significance levels of the tested variable at the top of the table in a two-way test with the second variable on the left.

Second Variable	Tested Variable				
	Beaufort	Cloud cover	Surface penetr.	Area	Year
Beaufort	---	P<.025	P>.25	P<.005	P>.995
Cloud cover	P<.05	---	P>.25	P<.001	P>.10
Surface penetr.	P<.01	P<.025	---	P<.001	P>.25
Area	P<.01	P<.025	P>.10	---	P>.50
Year	P<.025	P<.025	P<.05	P<.005	---

Table 2. Table of results of weighted ANCOVA.

Source	D.f.	Sum of Squares	Mean Square	F Value	Prob. > F
Model	9	10.2170	1.1352	9.11	0.0001
Beaufort	2	1.9594	0.9797	7.87	0.0007
Area	3	7.0483	2.3494	18.86	0.0001
Cloud cover	3	2.1789	0.7263	5.83	0.0010
Year	1	0.0010	0.0010	0.01	0.9305
Error	101	12.5803	0.1246		

Table 3. Parameter estimates for 1986-88 data. Obtained with analysis of covariance procedure GLM (SAS statistical package). Number of kilometers flown is used as weighting factor for weighted analysis.

Parameter	Description	Unweighted	Weighted
$\bar{P}$	MEAN	.0283	.0314
α_{B1}	BEAUFORT 1	.0113	.0161
α_{B2}	BEAUFORT 2	.0081	.0068
α_{B3}	BEAUFORT 3	-.0193	-.0229
α_{A1}	AREA 1	-.0090	-.0135
α_{A2}	AREA 2	-.0247	-.0341
α_{A3}	AREA 3	.0271	.0301
α_{A4}	AREA 4	.0067	.0175
α_{S1}	CLEAR SKY	.0166	.0222
α_{S2}	SCATT. CL.	-.0025	-.0067
α_{S3}	MOSTLY CL.	-.0047	-.0005
α_{S4}	OVERCAST	-.0094	-.0150
β	YEAR	.0038	-.0004

Table 4. α and β errors based on 100 random data sets for each combination of year and change (300 data sets for the data simulating three years with no change). Values in the top section of the table reflect β-errors; values in the lower portion reflect α-errors.

No. of years	% change	β-error associated with given α-error α=.05	α=.10	α=.20	α=.30	α=.40	α=1.0
4	-50	.11	.05	.02	.01	.01	.00
6	-50	.06	.03	.03	.01	.00	.00
4	+50	.52	.35	.25	.20	.17	.05
6	+50	.39	.32	.22	.16	.15	.01
4	-25	.74	.66	.50	.41	.32	.11
6	-25	.61	.52	.40	.28	.25	.04
4	+25	.85	.71	.60	.48	.41	.18
6	+25	.75	.65	.45	.39	.30	.07

		Actual α-errors for α=.05	α=.10	ratio of +/- estimates
3	none	.05	.10	50/50
4	none	.04	.08	50/50
6	none	.07	.12	58/42

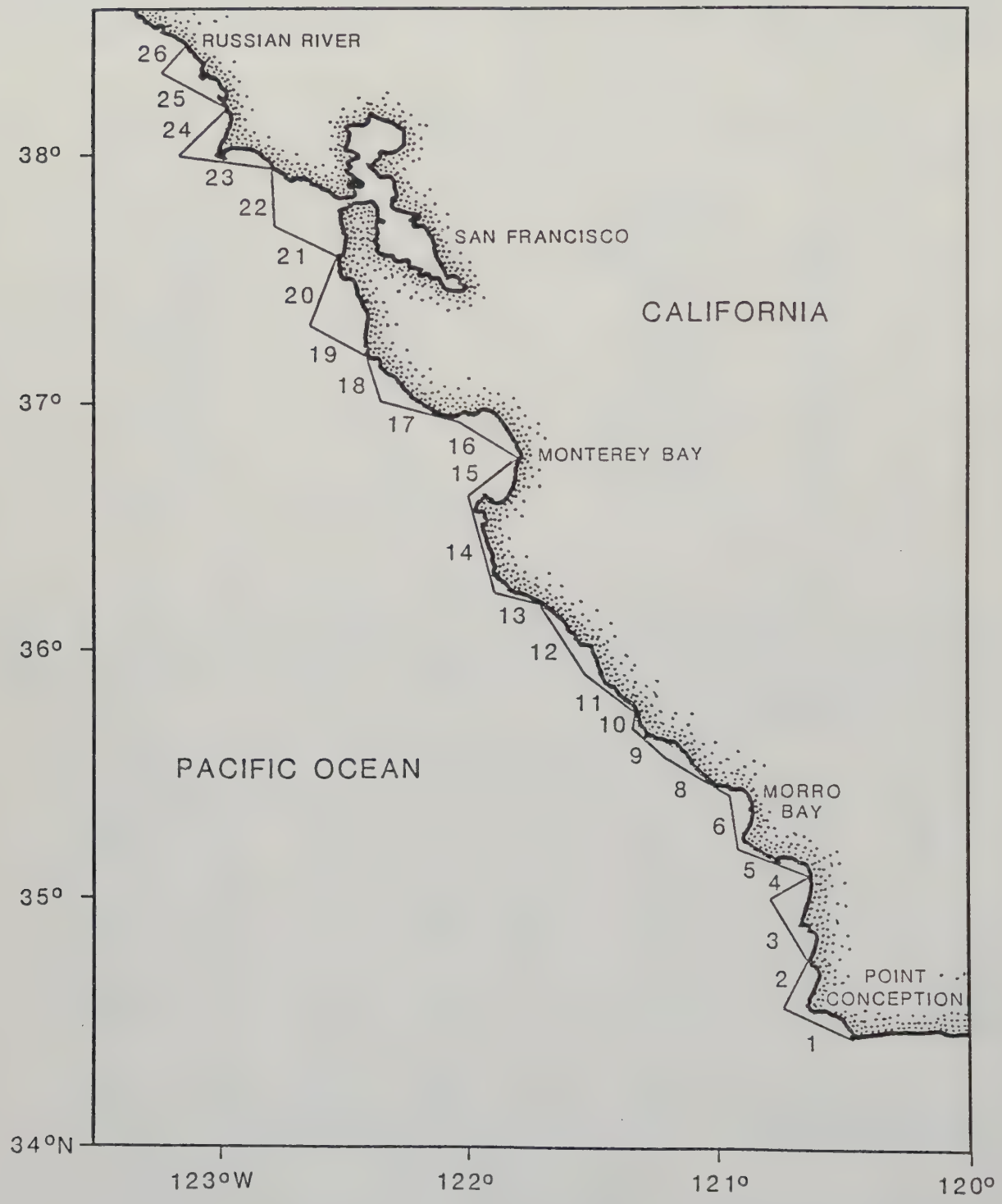

Figure 1. Flight transects for aerial survey of harbor porpoise 1986-88. Transect 7 was combined with transect 8 after 1986 and is not shown.

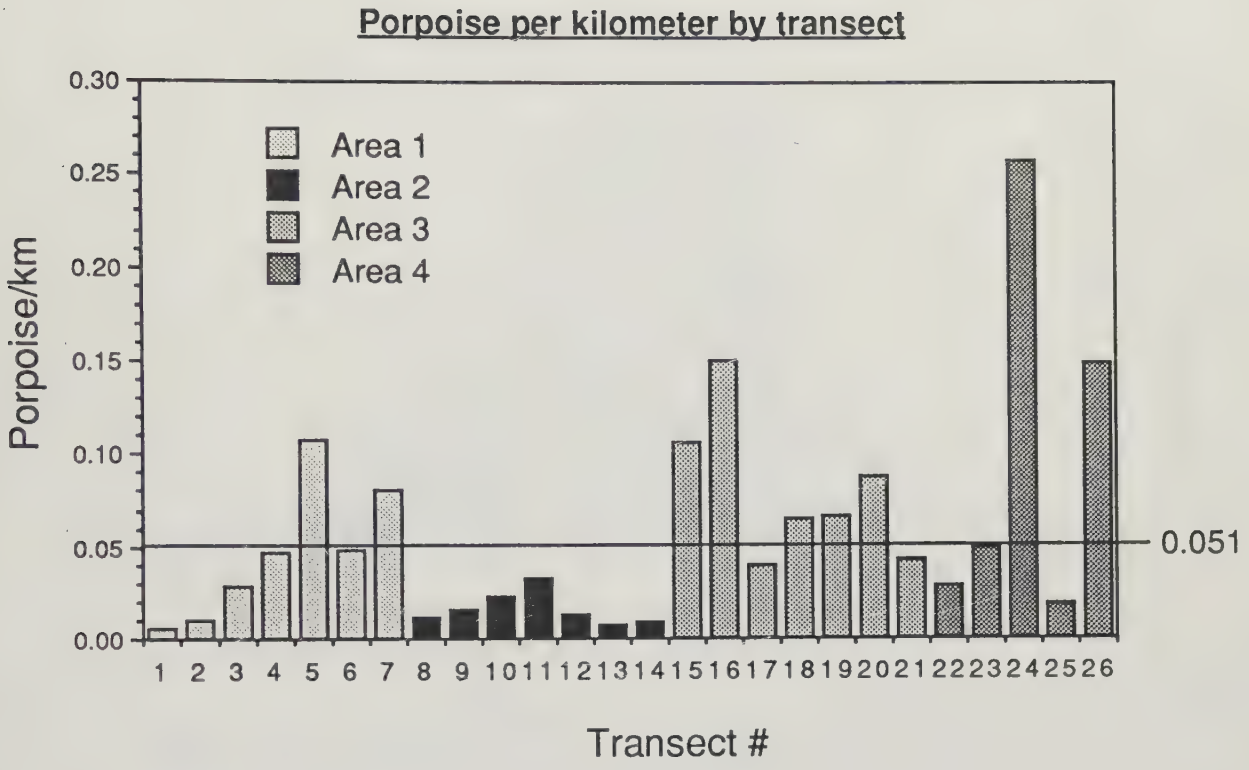

Figure 2. Porpoise per kilometer by transect. Based on flight segments with Beaufort sea states of 1 or 2 only. Mean value is 0.051. Four approximately equal areas were chosen as follows: average abundance (Area 1), below average abundance (Area 2), above average abundance (Area 3), and highly variable abundance (Area 4).

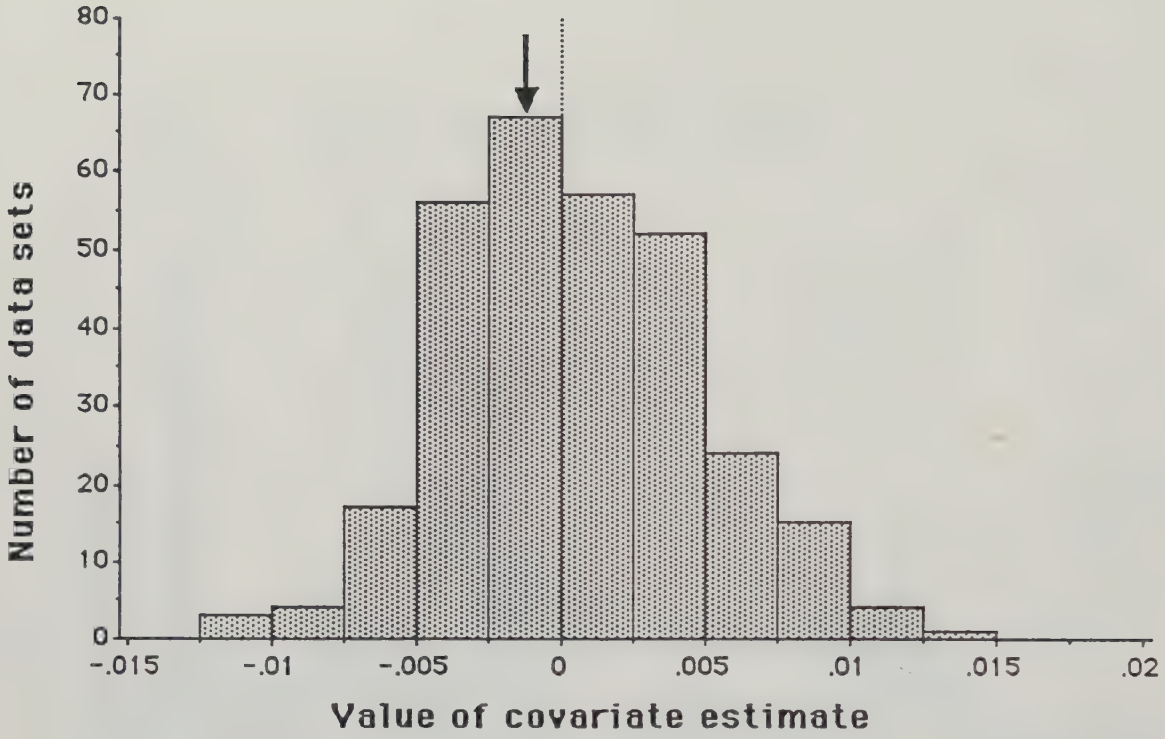

Figure 3. Distribution of 300 covariate estimates from simulated data for 3 years with no yearly trend in abundance. The arrow shows the approximate location of the actual 1986-88 covariate estimate (-.0004) for weighted analysis.